

Broadband Field Directionally Mapping using Maneuverable Acoustic Sensor Arrays

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LONG-TERM GOALS

The long-term goal of this research is to develop passive array detection and localization techniques for towed sonar platforms that are robust to platform maneuvers. A general research component that will further this goal is development of accurate noise field estimation techniques.

OBJECTIVES

Current passive sonar methods are designed for static fixed or straight towed arrays. Signal processing approaches for such systems are thus seriously degraded by platform maneuvers. In this project, the objectives are to: 1) exploit small platform maneuverability using small broadband acoustic arrays to resolve targets from interferers, and 2) improve the target detection, localization, and tracking performance of long arrays during tow-ship turns. To address these objectives, noise field estimation techniques in the context of array maneuvers are being studied and developed.

APPROACH

To produce an adequate estimate of the noise field it is necessary to overcome several obstacles that result from noise in the system, and an ill-posed grid, among other issues. In a direct implementation of the Expectation-Maximization (EM) algorithm we produce an estimate of the noise field using

$$\hat{\Sigma} = \underset{\Sigma}{\operatorname{argmax}} L(\mathbf{x}(n), \dots, \mathbf{x}(n - N + 1), \Sigma)$$

Where $\hat{\Sigma}$ is a diagonal matrix containing the noise power associated with each grid point, $\mathbf{x}(n), \dots, \mathbf{x}(n - N + 1)$ is the data associated with the most recent N snapshots and $L()$ is the likelihood given both the data and the diagonal of the noise covariance matrix. One avenue to producing a better estimate is to employ some of the regularization techniques outlined in [1]. Specifically we can use a modified form of the EM algorithm (the so-called “method of sieves”) where we determine $\hat{\Sigma}$ indirectly by fitting a series of splines. In this case we are solving a slightly different problem:

$$\hat{\alpha} = \underset{\alpha}{\operatorname{argmax}} L(\mathbf{x}(n), \dots, \mathbf{x}(n - N + 1), \alpha)$$

where

$$\hat{\Sigma} = \sum_{\text{all } m} \hat{a}_m * \Psi_m$$

Each Ψ_m represents a diagonal matrix of the same dimension as $\hat{\Sigma}$ that is constructed using a spline whose length is much less than the dimension of $\hat{\Sigma}$. This approach leads to a more regular estimate of $\hat{\Sigma}$ that may be more useful in some scenarios. We can observe the difference in performance for these two methods. Figure X shows the results of the traditional EM algorithm and the spline fit (using third-degree B-splines) EM algorithm. Both algorithms were run using a simulated 30 element acoustic vector sensor array with 900 snapshots.

Attention has also been directed at the impact of varying the array tilt in order to maximize array gain for selected look angle. Some scenarios may allow the tow vessel speed to vary when operational considerations preclude a change of heading.

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WORK COMPLETED

Implementations of the EM algorithm have been written and applied to the case of noise field estimation in the towed passive sonar context, and development of those algorithms is still underway. Array gain improvements due to array tilt have also been simulated for deep water.

RESULTS

Fig. 1 illustrates an application of the EM algorithm with the “method of sieves” regularization. Fig 1(a) shows an example noise field power distribution. Snapshots of noise are generated from this distribution, and Fig. 1(b) is a estimate from the method of sieves. The estimated power distribution is seen to exhibit good agreement in shape and overall level when compared to the true power distribution.

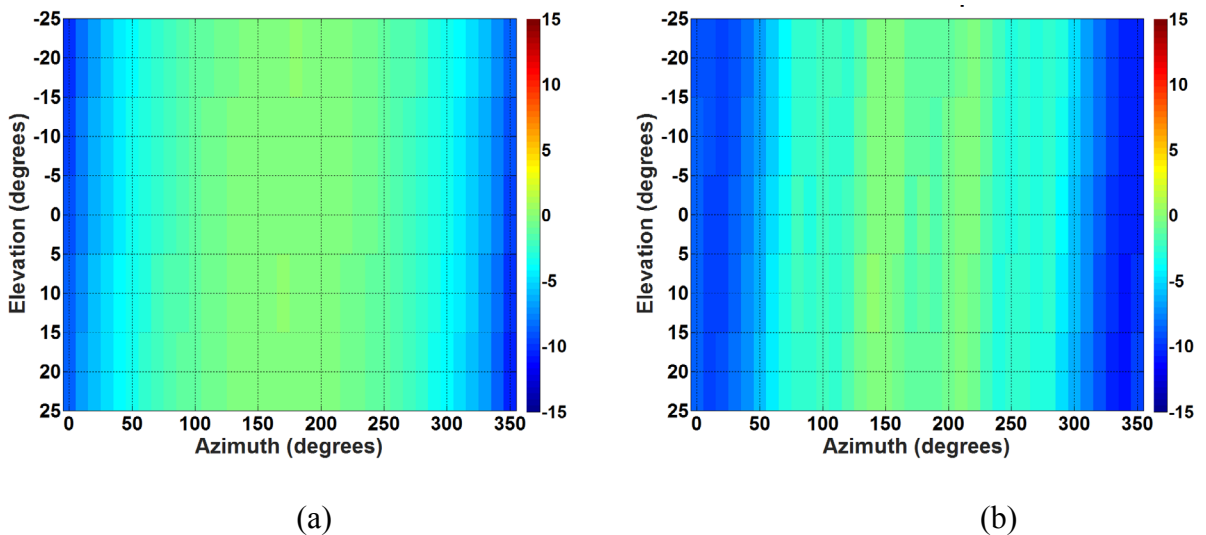


Figure 1: (a) True power distribution of a notional noise field, (b) Power distribution estimate from EM algorithm with “method of sieve” regularization.

To see that regularization is necessary, Fig. 2 shows the result from the same data with an implementation of the EM algorithm that lacks regularization. The resulting power distribution estimate does not agree very well with the true distribution seen in Fig. 1(a).

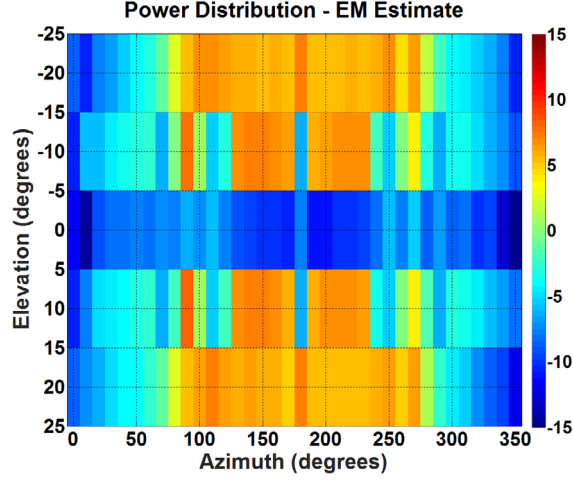


Figure 2: Power distribution from EM algorithm with no regularization: the true distribution is shown in Fig. 1(a).

Fig. 3 shows array gain as a function of look direction and array tilt for an array with $\lambda/2$ spacing. The gains are relative to a non-tilted horizontal array. Fig. 3(a) shows array gain for a 50-element array, and Fig. 3(b) shows gain for an array with 100 elements. These two plots illustrate that the gains available in this setting are fairly modest even for a 100-element array, rarely exceeding ± 5 dB.

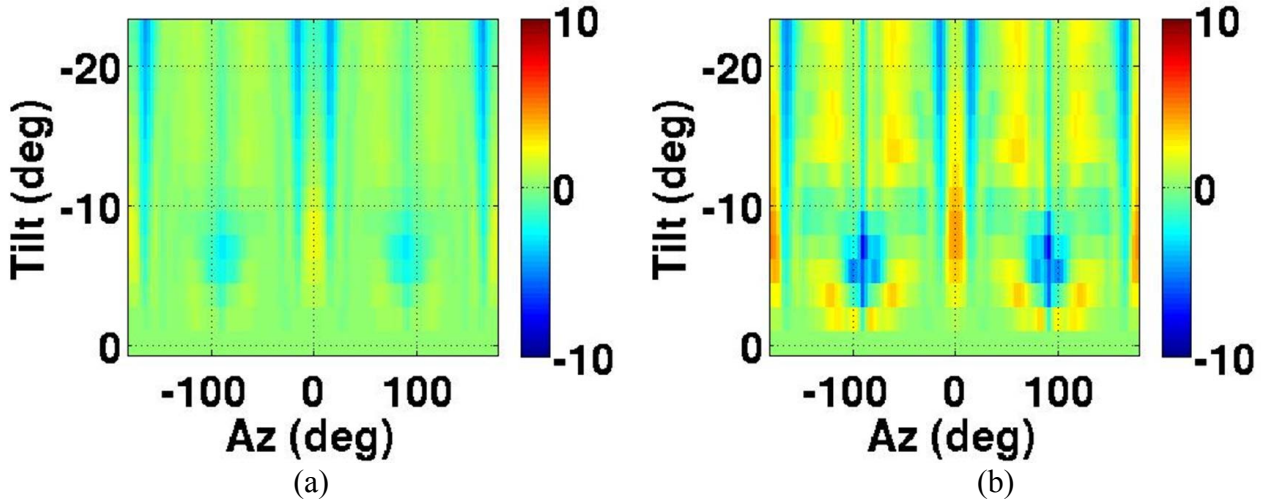


Figure 3: Array gain vs. horizontal array as a function of look direction and tilt. (a) 50-element array, (b) 100-element array

In summary, the significant results/conclusions are:

- a) Using the EM algorithm for noise field power estimation with seems to require a good regularization method. Simulation suggests that the “method of sieves” is a good approach.
- b) Attempts to exploit vertical noise structure (with an eye towards using array tilt to get better “looks” at the noise and/or target) produced disappointing results. Tilting the array does not provide good noise separation if signal and noise have similar vertical structure.

IMPACT/APPLICATIONS

The potential impact of this research is improvement in target detection/localization in the challenging regime of maneuvering towed sonar receiver arrays.

REFERENCES

- [1] A.D. Lanterman, "Statistical radar imaging of diffuse and specular targets using an expectation-maximization algorithm." *AeroSense 2000*. International Society for Optics and Photonics, 2000.